Length-extension LGS microresonators for FM-AFM: microfabrication and shear effects sensitivity

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Length-extension resonators have already been studied in order to make cantilever beams for frequency-modulation atomic force microscopy (FM-AFM). In this paper, theoretical investigations are given in order to improve the design of such devices using this vibrating mode. The study is focused on the shear effects which lead to a loss of resolution for application in atomic force microscopy. Performances of resonant devices in LGS and Quartz are compared using analytical and finite element methods. The second part of the work concerns the microfabrication of the devices. Using a process based on the anisotropic chemical etching, a monolithic length extension resonator with a tip at its end is obtained which constitutes a real advantage in regard to the existing piezoelectric probes. We proved that the process leads to successful LGS devices with good electrical characteristics.

I. Theoretical considerations

Preliminary comparison of quartz and other piezoelectric crystal resonator performances was obtained via analytical theoretical considerations. As seen in Fig.1, the device was modeled using the COMSOL Multiphysics® software in accordance with the actual dimensions to get results closest to reality. The vibrations of a beam in extension, the effects of rotation in the crystal plane of the devices and the effects of a change in geometry were studied in the case of LGS devices. A static analysis was conducted to identify the effects of anisotropy of the material. Indeed, during a tension-compression along Y-axis, the LGS beam undergoes bending along the X-axis due to its anisotropy. We show in this study that this shear effect is due to the rigidity coefficient s_{14} which is different from zero. Observation of this phenomenon is given in this paper by modeling a sensor used in Frequency Modulation Atomic Force Microscopy [1]. Further calculations were then conducted to explore the evolution of the coefficients involved in the shear effects for beams aligned along a direction which is in the YZ plane. As an example, Fig. 2 gives the evolution of the s'_{14} coefficient when the alignment of the beam varies in YZ plane. As seen, the evolution is different according to the materials but for each crystal two angles allow to cancel the coefficient: θ=-63° and θ=28°. This study was carried out for all coefficients involved in shear effects and results were analyzed. If we do not cancel coefficients, devices will be powered by a movement which is a combination of extension and flexion due to inherent properties of the material. This bending will lead to a loss of resolution for application in microscopes. So, thanks to the results given in this paper, a suitable geometry of device is obtained to minimize shear effects and to improve microscopes probes performances.

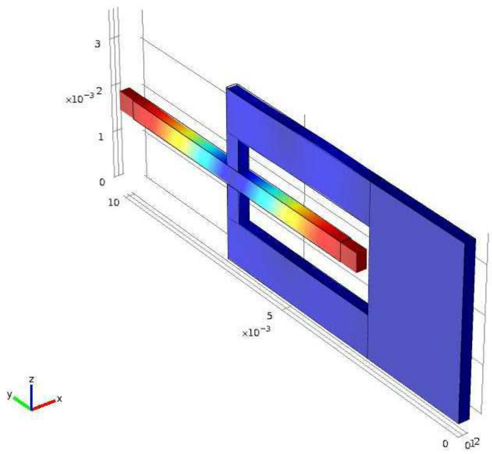

Fig. 1: FEM simulation of the resonator vibrating in length extension mode. The beam is aligned along Y-axis

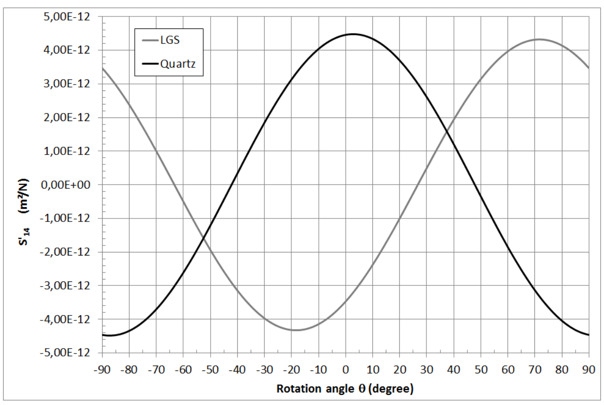

Fig. 2: Evolution of s'_{14} coefficient with the rotation angle θ around X axis.

II. MICROFABRICATION

Preliminary to the devices fabrication a systematic study of X Y and Z cuts was performed in order to determine the etched rates, the lateral underetch under the mask and the shape of the tip at the end of the beam. LGS etched samples characteristics with several solutions based on HF, HCl, HNO_3, H_3PO_4 and H_2SO_4 were compared [3]. A selection of an anisotropic etchant with relatively high values of etch rates is necessary to fabricate the devices. HCl based solutions even if they yield to rough surfaces have important advantages for device processings. In particular, these solutions give the highest anisotropic factor. Moreover this acid doesn't induce film formation at the surface of the LGS samples. So, this acid was retained as etchant for the fabrication of the micro resonators. The length extension devices were micromachined in a monocrystal square X plate (38 mm). The lengths of the beam were oriented by an angle θ from the Y orientation according the theoretical results (+/- 10°C). The fabrication process was divided into five main steps: metallic mask deposition, photolithography for electrodes design, SiO_2 deposition, photolithographic process for the devices design, chemical etching. Fig.3 shows the LGS plate just before the etching process. Because of the initial thickness of the LGS plate, the etching time was

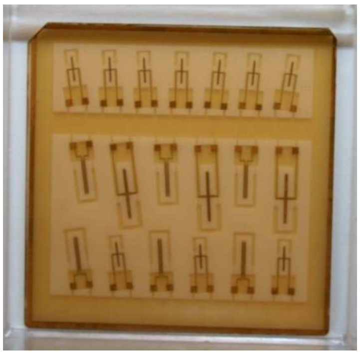

Fig. 3: FEM Langasite plate after the second photolithographic step.

around 6 hours at a constant temperature of 60°C. After the etching step, the devices were separated from the carrier. Using the appropriate design of the SiO_2 mask, a tip was directly obtained at the end of the beam as shown in Fig. 4. The tip could be used directly as the AFM sensor instead of the tungsten wire. Eliminating this last step of fabrication can significantly reduce the cost of the resonators.

III. CHARACTERIZATION OF RESONATORS

Before the electrical characterization of the device, we controlled the dimensions and the shapes of the resonators and the tips. Length and width of the beam are consistent with expectations. The shapes of the tips results from blocking facets during etching. Then, using a network analyzer, we determine the amplitude and phase spectra of the resonant device. The resonant frequency f_R=420 kHz of the fundamental length extensional mode of vibration is in agreement with the theoretical results [4]. Motional parameters and quality factor in air were determined. The quality factor was about 2000, which corresponds to the same order of magnitude as in quartz. Temperature sensitivity were also

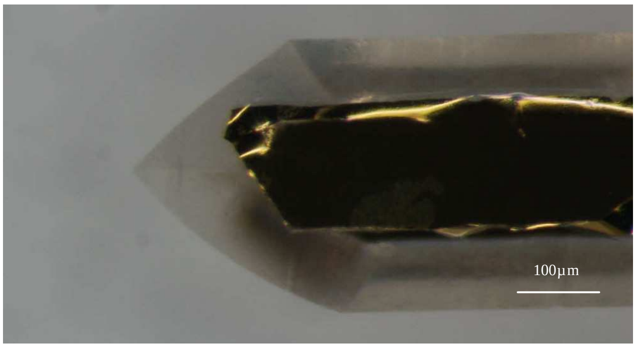

Fig. 4: Optical images of the beam and its tip. The metallic mask was not removed which allows to see the under etching.

measured. The results confirmed the frequency-temperature behavior of the devices [4]. To check the magnitude of the shear vibration and measure the dynamics and topography of the resonators, we will use the MEMS analyzer (Polytec). These measurements will be performed soon to verify the theoretical results given above.

IV. CONCLUSION

LGS is of real interest to enhance the performances of the FM-AFM probes. Indeed, it has been demonstrated that two temperature compensated cuts exist for length extension modes of vibration and that a specific design should eliminate the coupling with a shear mode. Moreover, we prove that the microfabrication using a batch low cost process can be used to obtain resonators with good electrical performances. The formation of the tip at the end of the beam is a real advantage of this process of fabrication. Additional measurements will be done to ascertain the shear effects that should affect the signal quality obtained by AFM.

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